崇新学堂

2024 — 2025 学年第一学期

实验报告

课程名称：Introduction to EECS Lab

实验名称：HW3-Head Light

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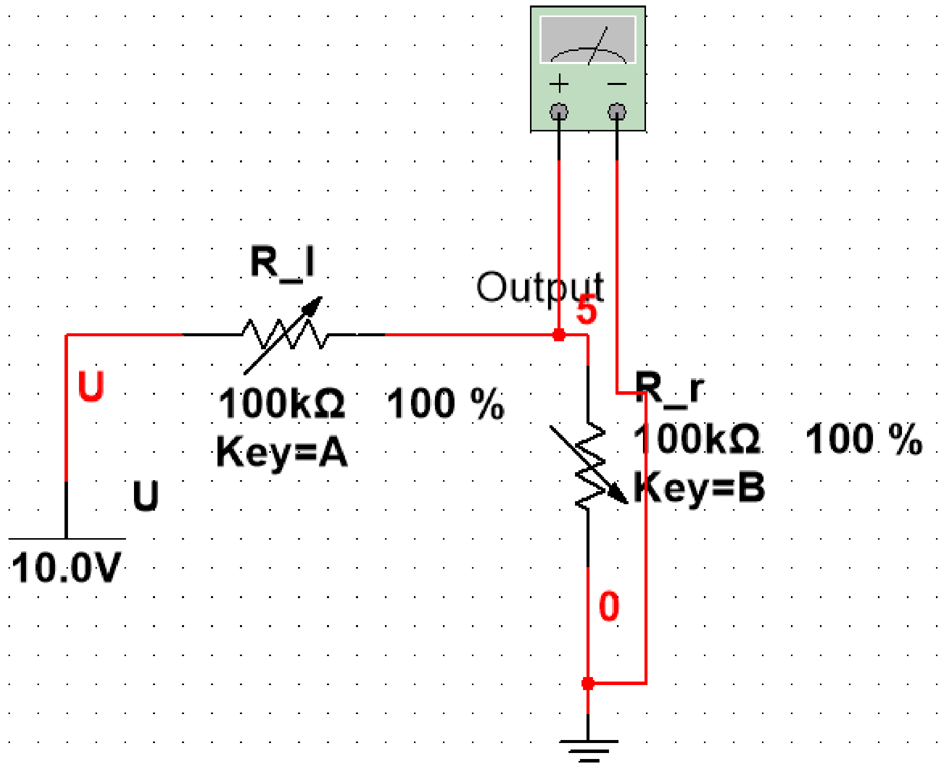
Homework 3

1. Introduction

The goal of this homework assignment is to design an electronic circuit for steering the head motor to seek and track a light source, using the photoresistive eyes as light sensors. This is like part 4 ("Show me the light!") of Design Lab 8, where you used a robot brain to provide feedback between the light sensed and the drive signal to the motor. But in contrast to Design Lab 8, the controller you will design for this homework assignment will be made entirely of electronic components – opamps and resistors –and no software.

2. Experimental step

Step 1: Design a Voltage Divider



As shown in the figure, we temporarily use a variable resistor as a photosensitive resistor, which makes it easier to adjust the resistance value for testing.

We can obtain the relationship between the output voltage and the resistance of the two photoresistors from the circuit diagram:

$$U_o = \frac{R_r}{R_l + R_r} U = \frac{1}{\frac{R_l}{R_r} + 1} \times 10V$$

Where $0 \leq \frac{R_l}{R_r} < +\infty$,so $0 < U_o \leq 10V$

So this divider can provide a voltage of 0~10V.

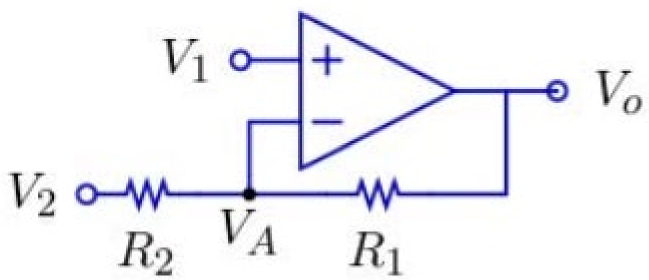
When facing the light source, the intensity of the light tends to be the same. Since we assume that the two photoresistors are the same, the voltage of the two resistors is evenly divided into 10V, which means the output voltage is 5V.

As the head turns counterclockwise, the light intensity received by the left photosensitive resistor gradually decreases, and the light intensity received by the right photosensitive resistor gradually increases. Then R_l gradually increases, and R_r gradually decreases, then $\frac{R_l}{R_r}$increases. According to $U_o = \frac{R_r}{R_l+R_r} U = \frac{1}{\frac{R_l}{R_r}+1} U$, the output voltage decreases.

As the head turns clockwise, we can use the same analysis method to determine that the output voltage increases.

Step 2:

Substep 1: Non-Inverting Amplifier



Regarding the circuit in the above figure: Since the amplifier is an ideal operational amplifier, it satisfies "Virtual Short" and "Virtual Open". Therefore, we can easily obtain$V_A = V_1$. The road from V_2 to $V_o$satisfies $\frac{V_2 - V_A}{R_2} = \frac{V_A - V_o}{R_1}$.Simplify this equation, we can obtain $V_o = \frac{R_1+R_2}{R_2} V_A - \frac{R_1}{R_2} V_2$. Considering $V_A = V_1$, we can transform the equation into the following form:

$$V_o = \frac{R_1 + R_2}{R_2} V_1 - \frac{R_1}{R_2} V_2$$

If $V_2 = 0$, we can get $V_o = \frac{R_1+R_2}{R_2} V_1$. From this equation, we can know:

$$K = \frac{R_1 + R_2}{R_2}$$

If $V_2 \neq 0$, and we use $V_o - V = K(V_1 - V)$ to express it, we can know that:

$$K = \frac{R_1 + R_2}{R_2} \qquad V = V_2$$

When $V_2 = 5V$and the value of V_1varies from 0V to 10V:

$$\frac{V_o - 5V}{V_1 - 5V} = K = \frac{R_1 + R_2}{R_2} > 1$$

We can understand that $V_o - 5V$ is k times that of $V_1 - 5V$.

So when V_1 increases from 0V to 10V, V_o will also increase.

V_1	V_2	R_1	V_O
10	5	100	10
7	5	100	7
5	5	100	5
3	5	100	3
0	5	100	0
10	5	10,000	10
7	5	10,000	9
5	5	10,000	5
3	5	10,000	1
0	5	10,000	0

Non-Inverting Amplifier's Data(rounded to an integer)

Substep 2: Inverting Amplifier

This circuit diagram is consistent with the circuit diagram of Substep 1, so the calculation process is similar and will not be elaborated in detail.

$$V_o = \frac{R_1 + R_2}{R_2} V_1 - \frac{R_1}{R_2} V_2$$

When $V_1 = 0$:

$$V_o = -\frac{R_1}{R_2} V_2$$

$$K = -\frac{R_1}{R_2}$$

If $V_1 \neq 0$, and we use $V_o - V = K(V_2 - V)$ to express it, we can know that:

$$K = -\frac{R_1}{R_2} \qquad V = V_1$$

When $V_1 = 5V$ and the value of V_2 varies from 0V to 10V:

$$\frac{V_o - 5V}{V_2 - 5V} = K = -\frac{R_1}{R_2} < 0$$

$K < 0$, so when V_2 increases, V_o will decrease.

V_1	V_2	R_1	V_O
5	10	5000	2.5
5	7	5000	4.0
5	5	5000	5.0
5	3	5000	6.0
5	0	5000	7.5
5	10	20,000	0.0
5	7	20,000	1.0
5	5	20,000	5.0
5	3	20,000	9.0
5	0	20,000	10.0

Inverting Amplifier'Data(rounded to one decimal place)

Substep 3: Summarize the above findings

When the head is pointing directly at the light, the controller's output should be 5V. We cannot use a simple

inverting or non-inverting amplifier as in the course notes to implement the control circuit, because they only has a single ended input, while we used a dual ended input in our experiment so that the circuit design has bidirectional behavior, which means that the motor can be able to turn both ways.

Step 3: Pick Good ks Values

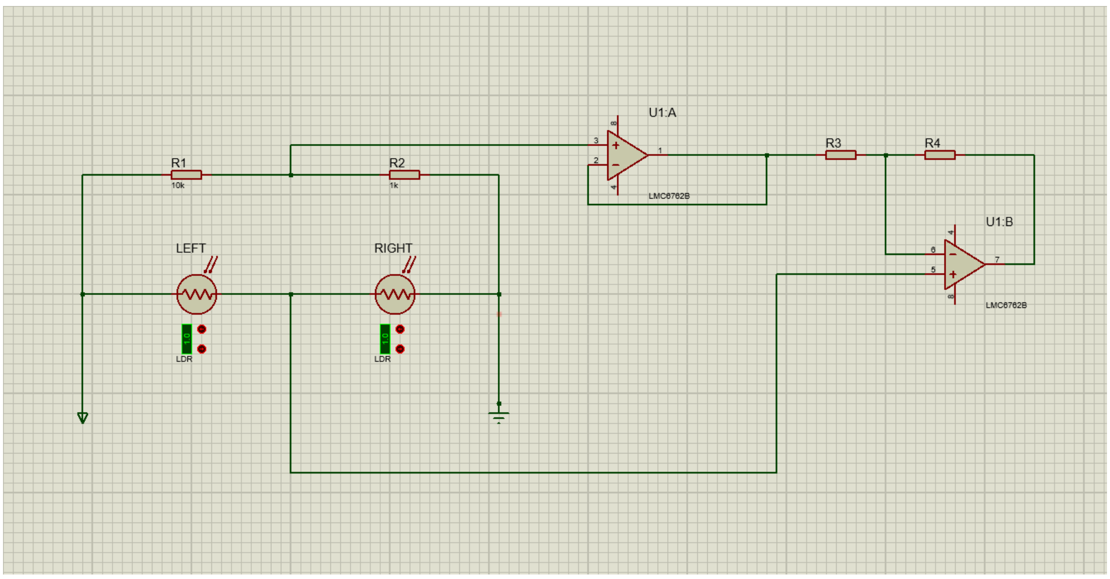
We obtained the corresponding main pole and kc value using the hw2 program.

```
>>> ================================ RESTART
>>>
(0.73333335181184145, 3.1999999999999829)
>>> ================================ RESTART
>>>
(0.73333336313565578, 1.5999999999999817)
>>> ================================ RESTART
>>>
(0.73484692283495268, 1.0999999999999812)
>>> ================================ RESTART
>>>
(0.73333337548018185, 0.79999999999998117)
```

k_s	Mag dominant pole	k_c
1	3.2	0.733
2	1.6	0.733
3	1.1	0.735
4	0.8	0.733

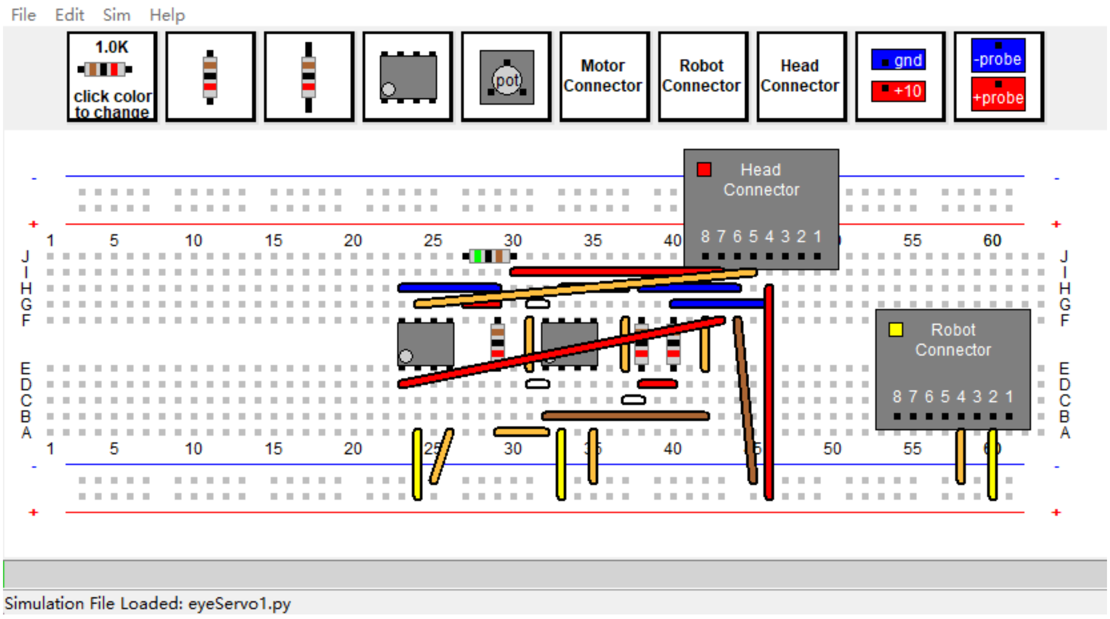
From the data obtained, we are supposed to choose$k_s = 4$.When k_s increases, it means that the input signal of the system (such as changes in light intensity) will become more sensitive or stronger. Therefore, in order to maintain system stability, the gain k_c needs to be appropriately reduced to prevent system overreaction or oscillation.

Step 4: Design a Controller Circuit



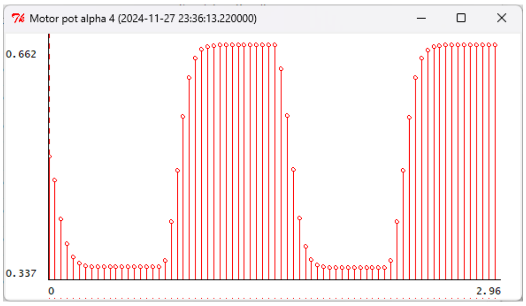
Controller Circuit

Step 5: Design a Suitable Circuit

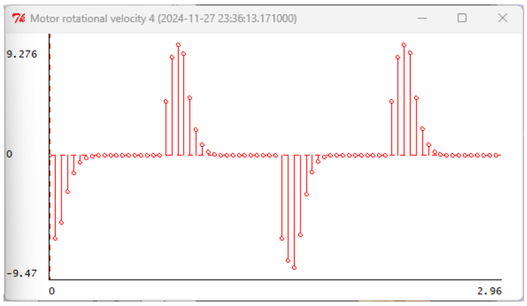


Circuit

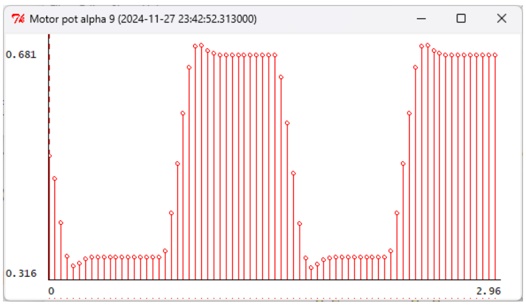
eyeServo 1:



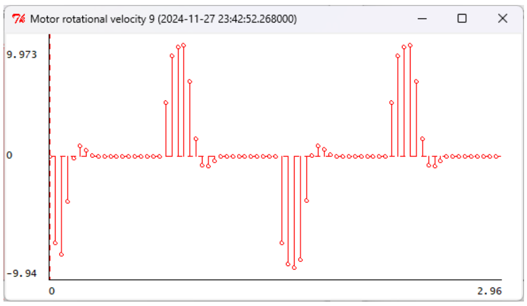
kc=0.5



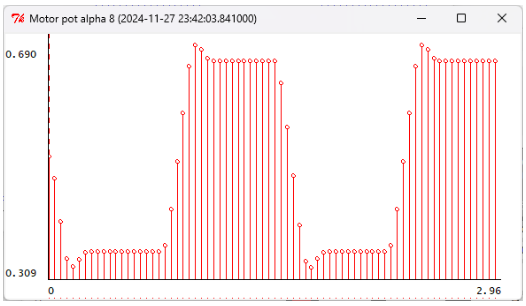
kc=0.5



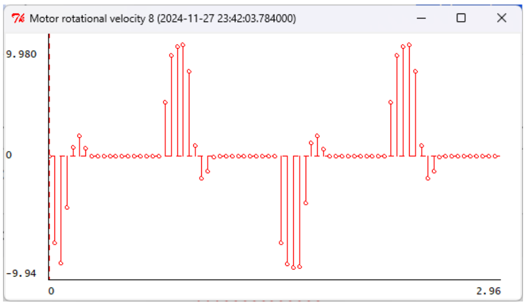
kc=2



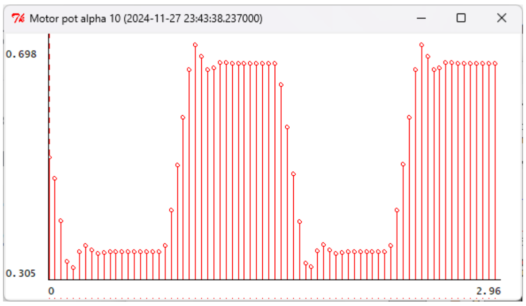
kc=2



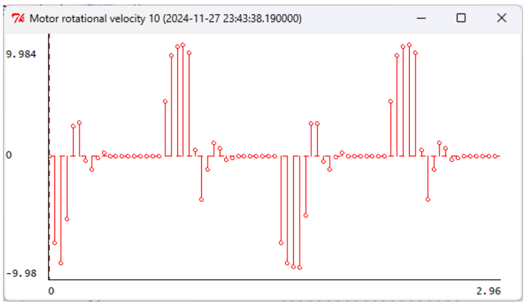
kc=3



kc=3

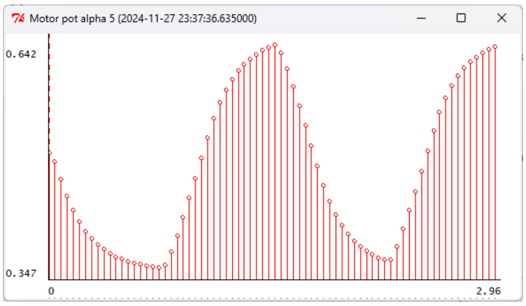


kc=5

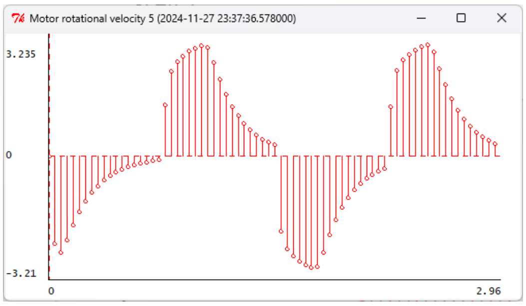


kc=5

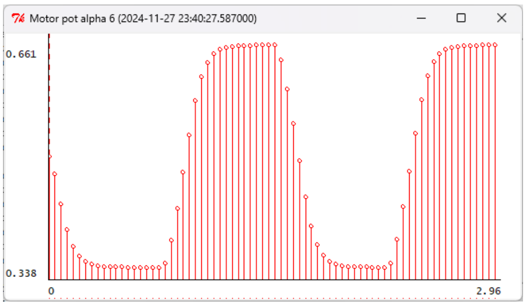
eyeServo 2:



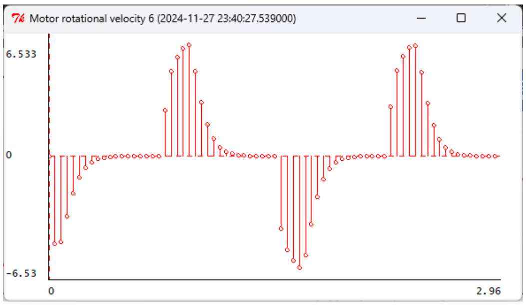
kc=0.5



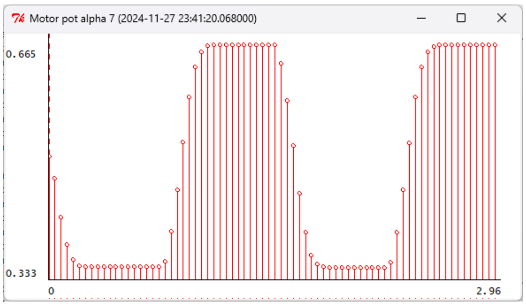
kc=0.5



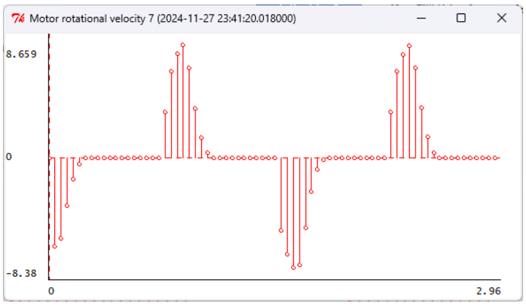
kc=2



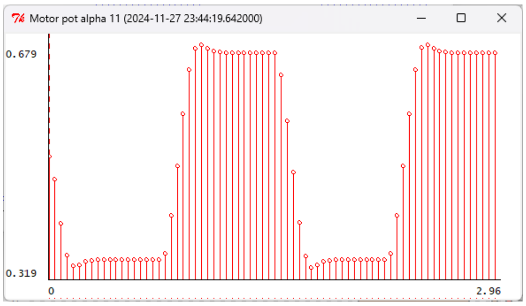
kc=2



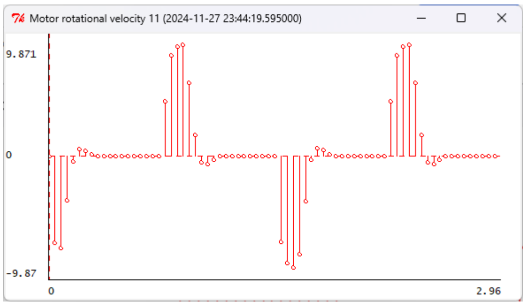
kc=3



kc=3



kc=4



kc=4

Circuit Code

```
#CMax circuit
head: (49,5)--(42,5)
opamp: (32,12)--(32,9)
wire: (46,8)--(40,8)
resistor(1,0,2): (40,9)--(40,12)
resistor(1,0,2): (38,9)--(38,12)
wire: (44,7)--(38,7)
wire: (38,13)--(40,13)
wire: (38,14)--(37,14)
wire: (37,12)--(37,9)
wire: (37,7)--(33,7)
wire: (32,8)--(31,8)
wire: (31,9)--(31,12)
wire: (31,13)--(32,13)
wire: (32,15)--(42,15)
wire: (42,12)--(42,9)
wire: (32,16)--(29,16)
resistor(1,0,2): (29,9)--(29,12)
wire: (29,8)--(27,8)
wire: (30,6)--(43,6)
opamp: (23,12)--(23,9)
wire: (29,7)--(23,7)
wire: (45,6)--(24,8)
wire: (23,13)--(43,9)
wire: (24,16)--(24,20)
wire: (26,16)--(25,19)
wire: (33,16)--(33,20)
wire: (35,16)--(35,19)
wire: (46,7)--(46,20)
wire: (45,19)--(44,9)
robot: (61,15)--(54,15)
wire: (60,16)--(60,20)
wire: (58,16)--(58,19)
resistor(5,0,2): (27,5)--(30,5)
```

CMax Code

3. Summary

This assignment builds upon previous work designing a robot head controller that turns towards a light source. Instead of using software, this homework focuses on designing a purely analog circuit using op-amps and resistors to achieve the same functionality. The assignment is split into two main parts:

Sensor Design: Students design a light sensor circuit using photoresistors to generate a voltage signal proportional to the difference in light intensity between two sensors. The goal is to create a signal independent of overall light intensity. This involves analyzing the voltage range produced by the circuit and understanding its behavior as the robot head rotates.

Controller Design: Students design an analog control circuit (a proportional controller) using op-amps to take the sensor signal as input and drive a motor to turn the robot head toward the light source. The design must ensure fast response, stability, uniformity (performance independent of light brightness and distance), and accuracy. This involves selecting appropriate gain values and considering the limitations of op-amps. The final circuit is simulated and tested using CMax software.